Predicting Wildfire Behavior in Black Spruce Forests in Alaska

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Abstract

The current fire behavior system, when properly adjusted, accurately predicts forward rate of spread and flame length of wildfires in black spruce (*Picea mariana* (Mill.) B.S.P.) forests in Alaska. After fire behavior was observed and quantified, adjustment factors were calculated and assigned to the selected fuel models to correct the outputs to more nearly coincide with observed values. Spotting distance models predict maximum spotting distances if some corrections and assumptions are made. Field-tested procedures are described.

Keywords: Fire behavior (forest), Alaska, black spruce, *Picea mariana*.

Dependable predictions of fire behavior are essential for making tactical plans for suppressing wildfire. Fires in Alaska's black spruce (*Picea mariana* (Mill.) B.S.P.) forests pose some unique problems in prediction.

In recent years, the current fire behavior system—Rothermel (1972) fire spread model—has gained acceptance as an accurate means of predicting fire behavior. Although the field-usable (Albini 1976) version of the model, in the form of nomographs, provides flexibility, some situations are not adequately described by the 13 stylized fuel models. In such cases, adjustment and adaptation of the model are necessary before fire behavior can be accurately forecast. The typical black spruce/ feathermoss (*Picea mariana/Hylocomium splendens-Pleurozium schreberi*) forests of Alaska present such a problem.

The first documented attempt to use the Albini nomographs to predict wildfire behavior was made in 1977, when I was fire behavior officer for a fire in an area of black spruce near the village of Hughes in interior Alaska. The fire burned for several days, traversing slopes that ranged in steepness from flat to 32 percent under a variety of weather conditions. The fire burned as a surface fire, presenting an ideal opportunity for measuring rates of spread and flame lengths under varied conditions of slope and fuel moisture content. In addition, the availability of an accurate experimental prototype model of a microwave fuel moisture meter (McLeod 1976) made it possible to measure the moisture content of fuels collected near the fire. Temperature, relative humidity, and the velocity and direction of the wind were measured hourly and when fuel samples were collected. Everything necessary to document fuel conditions and fire behavior was available for comparison with values calculated by the Albini nomographs.

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The comparison procedure used is conceptually simple but is difficult to perform under field conditions. The first step was to use weather variables to calculate the moisture content of 1-hour timelag fuels (less than ¼-inch diameter). At the same time, fuel samples were gathered and their moisture content was measured with the microwave fuel moisture meter for comparison with calculated values. This step was necessary because a large percentage of the fine fuels in this fuel type is live material that behaves more like finely divided dead fuel, and the procedures for calculating fuel moisture apply to dead fuels only. The often deep, spongy layer of feathermosses and lichens has an enormous surface-to-volume ratio (estimated at 4,300:1 square foot per cubic foot).[1] Because the feathermosses have tiny, long, filamentous rhizoids that transport soil water remarkably long vertical distances to green surface tissues, mosses (and lichens) respond to atmospheric moisture and temperature as if they were dead fuels. Of perhaps even greater importance is the rapid rate of response of these fuels, which is caused by the high surface-to-volume ratio. These fuels take only minutes to reach equilibrium moisture content when the relative humidity changes (Mutch and Gastineau 1970). This is important when fire behavior is predicted, because changes in relative humidity have an almost immediate effect on fire behavior. In this test, the calculations of fine fuel moisture content agreed closely with the measured values.

The next step was to record the rate of forward spread and flame length, along with slope steepness, wind velocity and direction, temperature, and relative humidity. None of the many methods that have been used to measure rate of spread is entirely satisfactory. In this case, the fire could be observed from either flank, and the simple method of timing its progress between points was used. Distances between timing points were measured after the fire passed and the area cooled down. Thirty-one such measurements were made over 5 days. Fortunately, a wide range of weather conditions allowed a reasonably reliable test of the fire spread model.

The question was, would any of the 13 available fire behavior fuel models predict what was being observed? The stylized fuel model 6 suggested by Albini (1976) was the first one I tried. Measured input variables from the fire site, and the nomograph for fuel model 6 (dormant brush model) were used to calculate rate of spread and probable flame length. Model 6 considerably overpredicted both rate of spread and flame length. At that point the best approach appeared to be to try the other 12 fuel models to determine if one of them would predict the fire behavior observed. The result of this trial-and-error process was the discovery that fuel model 9 (hardwood litter model) gave values consistently close to the observed rate of spread. Plotting observed versus measured values produced the nearly linear relationship shown in figure 1. Calculation of simple linear regression led to the tentative conclusion that the rate of spread predicted by fuel model 9, if multiplied by the constant 1.2, would yield values very close to the rate of spread observed in black spruce/feathermoss forests, provided fire continued to spread as a surface fire and did not exhibit erratic behavior, such as spotting ahead or moving as a running crown fire.

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[1] James K. Brown, Northern Forest Fire Laboratory, Missoula, Montana, personal correspondence, 1977.
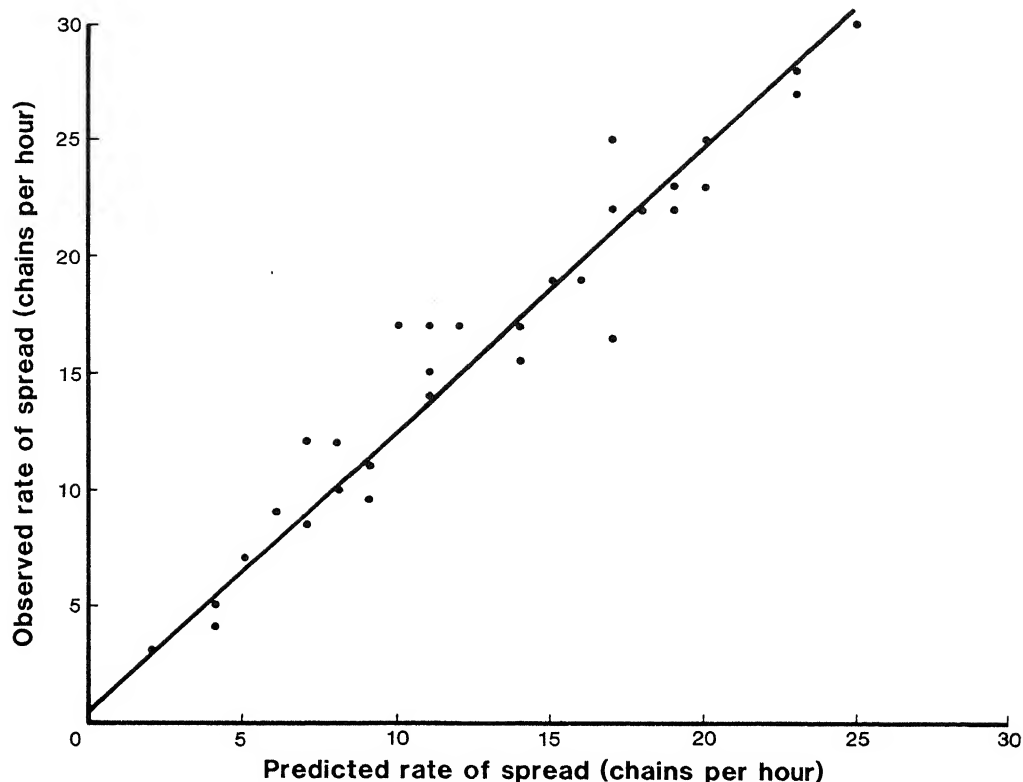
Figure 1.—National Forest Fire
Laboratory (NFFL) fuel model 9
predicts rates of spread that are
linearly related to observed
values.

The actual regression equation is:

$$Y = 1.2 + 1.18X;$$

where:

Y = observed rate of spread (chains per hour),
X = calculated rate of spread (chains per hour) using model 9, and
$r^2 = 0.94$.

The standard error is:

$$S_{y \cdot x} = 1.88.$$

The slope factor is significant at the 99-percent level. Because the Y intercept (when X=0) is small and a zero intercept is well within the 95-percent confidence limits, and because the purpose of this effort was to yield a practical procedure usable in the field, the simplification to Y=1.2X is justified and was subsequently used. This procedure, which was complemented by good spot weather forecasts, accurately predicted the rate of progress of the fire for several more days until it was controlled. Since that time, the procedure has been used many times to accurately predict behavior of fires in Alaska.

One other important characteristic of fire behavior remained to be described: flame length, which is directly related to fireline intensity. For tactical decisions about fire suppression, fireline intensity is as important as rate of spread.

Fireline intensity (often called Byram's intensity) is the rate at which heat is released per foot of fireline at the head of a fire (British thermal units (Btu) per second per foot). It is internationally recognized as a way to estimate the limits of control, as described by Hodgson (1968).

Estimates of flame length were noted, along with observations of rate of spread, for the fire near Hughes. Although flame length is more difficult to measure than rate of spread, visual estimates were made for 5-minute intervals and recorded, along with observed rates of spread. Using the same process with the nomographs, I found that fuel model 5 (short brush model) gave acceptably close estimates for flame length. All calculated and observed values are listed in table 1. The procedure for estimating flame length was not precise enough to justify a numerical analysis, but a simple correlation coefficient between calculated flame length and the average of observed values gave a correlation of 0.96. It should be noted, however, that the range of values for flame length (0 to 6 feet) is not large.

At the time the work was done, there were two fairly easy methods for estimating Byram's fireline intensity under field conditions. One is the procedure described by Albini (1976, p. 60) where rates of spread and the reaction intensity (Btu per minute per square foot) are combined. The second method, which works well if rates of spread are low (less than 10 chains per hour for fuel model 5), is to use the 13 stylized fuel model nomographs (Albini 1976) in a slightly modified way. The procedure is described in the appendix.

To estimate flame length, if you know the rate of spread, enter one of Albini's (1976) nomographs in the upper right-hand quadrant (such as the one shown in fig. 2) on the "dead fuel moisture" axis. Intersect the proper turning line and draw the first vertical line running down through the "fire intensity" axis (reaction intensity). Then construct a horizontal line, starting on the "rate of spread" axis, using a known rate of spread, and extend it to the right. The intersection of the two lines marks the value of flame length. Figure 2 converts flame length to Byram's fireline intensity. A combination of these two procedures gives a reaction intensity that, when combined with
tely predicts flame length. After considerable trial and
A value of 100 percent was used for the live fuel
seems to hold true for black spruce stands during
ка.

use a 20-foot windspeed and a built-in wind
nomographs and the recently developed TI-59
:ustom, read-only memory (Burgan 1979) require a
idflame height.

'7 fire season and for the next 3 years, I applied these
ed estimates on roughly a million acres of wildfire in
ı I used the procedures described, fuel model 9 gave
rate of spread (when multiplied by 1.2), and fuel
acceptably well.

Table 1—Observed and calculated variables of fire behavior in a wildfire in black spruce in Alaska

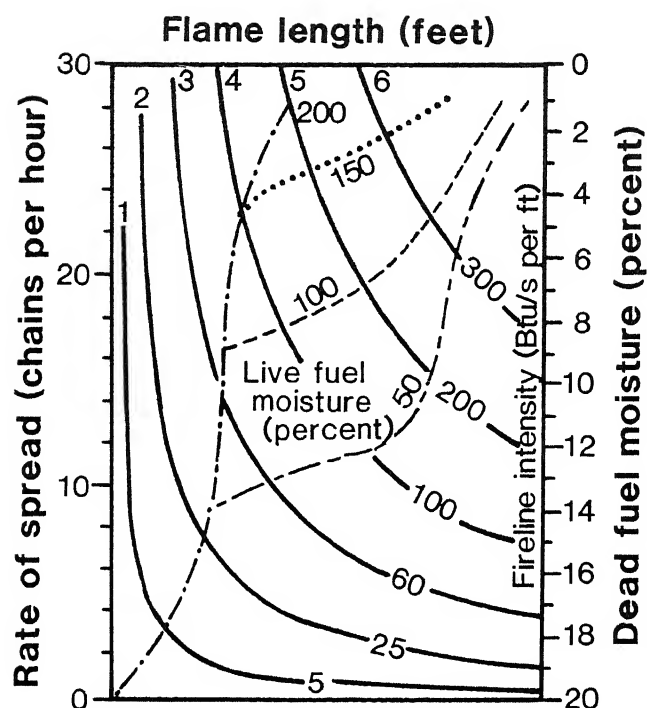| Rate of spread Observed	Rate of spread Calculated	1-hour fuel moisture content	Mid-flame wind-speed	Slope	Temperature	Relative humidity	Observed flame length	Reaction intensity	Calculated flame length
- Chains per hour -		Percent	Miles per hour	Percent	°F	Percent	Feet	Btu per minute per square foot	Feet
2	3	13	2	15	50	65	0 -1	929	1.0
4	4	10	3	20	68	35	1 -2	990	1.5
5	4	11	3	25	65	44	1 -2	978	1.5
7	5	7	3	25	76	25	2	2,296	2.5
8.5	7	10	5	12	68	35	2	990	2.2
9	6	14	5	10	50	65	2	883	1.9
9.5	9	6	5	15	71	38	2.5-3.5	2,652	3.6
10	8	7	5	15	71	38	2 -3	2,296	3.3
11	9	10	6	0	62	66	2 -3	990	2.4
12	7	6	4	15	70	37	2 -3	2,652	3.2
12	8	8	5	10	62	55	3	1,702	2.8
17	10	8	6	10	62	55	3	1,702	3.2
14	11	7	6	0	73	43	3 -4	2,296	3.8
17	11	7	6	0	73	43	3 -4	2,296	3.8
15	11	7	6	0	73	43	3 -4	2,296	3.8
17	12	9	7	10	65	57	1.5-2.5	1,001	2.7
15.5	14	8	7	25	64	52	3 -4	1,702	3.8
17	14	8	7	25	64	52	3 -4	1,702	3.8
25	17	7	8	10	68	41	4 -4.5	2,296	4.6
19	15	6	7	10	67	32	4 -4.5	2,652	4.6
19	16	6	7	25	67	32	4 -5	2,652	4.8
25	17	7	8	10	71	46	4 -5	2,296	4.6
22	17	7	8	10	71	46	4 -5	2,296	4.6
22	18	7	8	25	71	46	4 -5	2,296	4.8
22	19	4	7	20	76	24	4 -5	3,067	5.6
23	19	4	7	20	76	24	4 -5	3,067	5.6
23	20	8	9	5	73	50	4 -5	1,702	4.3
25	20	8	9	5	73	50	4 -5	1,702	4.3
27	23	9	10	20	70	56	3.5-4	1,001	3.7
28	23	9	10	20	70	56	3.5-4	1,001	3.7
30	25	5	9	10	71	28	5 -6	2,887	6.5

Flame length (feet)

Figure 2.—NFFL fuel model 5 can be used with a predetermined rate of spread to estimate flame lengths (see fig. 4 in appendix) in fires in black spruce forests in Alaska (from Albini 1976).

Although fires in Alaska black spruce most often burn in tree crowns, running crown fires are rare. The fire is carried by surface fuels, with a crown fire often following closely behind the fire front, giving the impression of a full-blown running crown fire. As a consequence, the limitation placed on the use of the fire spread model (Albini 1976) that the fire must be a surface fire is usually met in black spruce fires in Alaska when the fire is not spotting ahead. The fire spread model has predicted fire behavior accurately up to a windspeed of 22 miles per hour (20 ft) at a relative humidity of 25 percent. One fire became a running crown fire at that point. It was in a black spruce forest where the trees were about 10 feet apart, 20 feet tall, and the crown closure was roughly 60 percent. It was the only case of a true running crown fire I have observed in Alaska and illustrates one example of threshold conditions necessary to create such a fire.
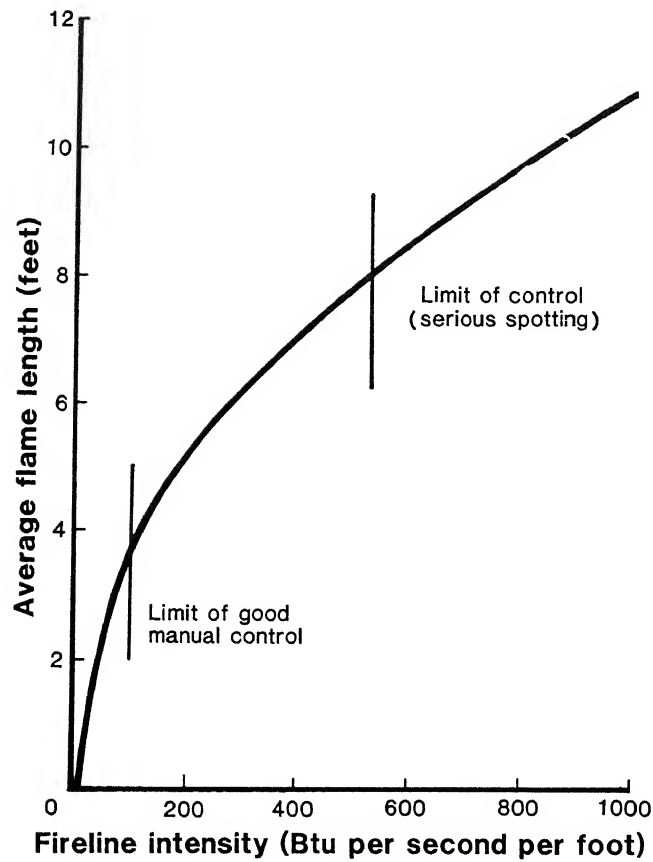
' forecasting in Alaska black spruce fuels would be
ϟpot fires and spotting distances. Because fires in
ꓱ burn in the crowns, ignition ahead of the fire front by
ꓱ. Although substantiating data are scanty and will
ϟfully predicted spot fire distances by using Albini's
imentation was necessary because the procedure
nber of trees burning simultaneously. In a typical fire in
s of trees are burning simultaneously. These form a

I have monitored weather conditions and observed spot fire distances on many occasions during 1977 and the years since. A suitable value for the number of trees burning simultaneously was found by using observed and measured conditions and by entering various values into Albini's procedure for determining maximum spot fire distances. In the absence of curves for black spruce, those for Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) serve well. If the fire consists of a long line of burning black spruce trees and you use six as the number of trees burning simultaneously, good estimates of spot fire distances are possible using the procedure described by Albini (1979).

Although fires in Alaska are sometimes much larger than those in the rest of the United States, the job of forecasting fire behavior is simpler in many ways. The fuels are often homogeneous and continuous for many miles. For most of the fire season, the long daylight hours prevent large diurnal changes in ambient temperature and relative humidity and lead to long periods of nearly constant burning conditions. The major carrier fuels (the moss-lichen layer) respond rapidly and predictably to relative humidity. The fire spread model and the procedures for estimating spot fire distances work well for estimating fire behavior. Consequently, fire behavior can be estimated many hours ahead. I commonly forecast fire behavior for the ensuing 7 or 8 hours under such circumstances, and in one emergency, successfully predicted the fire perimeter location 10 hours in advance, simply because conditions and fuels remained constant.

Summary

Fire behavior fuel model 9 (Albini 1976) should be used to predict rate of spread of fire in Alaska black spruce forests, with the result multiplied by 1.2. Fuel model 5 should be used to determine reaction intensity. Fireline intensity can then be determined by combining rate of spread and reaction intensity by the procedure described by Albini (1976, p. 60). Figure 3 can be used to convert fireline intensity to flame length if needed. For the newer nomographs (using midflame wind) or the TI-59, the fireline intensity and the flame length are read directly, using the rate of spread calculated from fuel model 9. Use of these procedures, coupled with good weather forecasts, yields remarkably accurate predictions of fire behavior in black spruce fires in Alaska.

Figure 3.—Flame length versus Byram's intensity. The limits of control are from Hodgson (1968).

Metric Units

1 square foot per cubic foot = 0.033 square centimeter per cubic centimeter
1 Btu per second per foot = 0.820 kilogram calory per second per centimeter
1 Btu per minute per square foot = 161.46 kilogram calories per second
                                                                 per square meter
1 chain = 20.1 meters
1 mile = 1.609 kilometers

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Appendix

Sample solution for estimating the behavior of fire in black spruce forests in Alaska:

Suppose conditions on a given day cause the moisture content of 1-hour timelag dead fuels to be 7 percent, the 20-foot standard wind velocity is 8 miles per hour, and the slope is 10 percent. To get the rate of spread, use the nomograph for fuel model 9 (Albini 1976) and follow the standard procedure to get rate of spread. If you are using the TI-59 or the 1979 nomographs, adjust the windspeed to midflame height. In this case, rate of spread is 6 chains per hour. Multiply this by 1.2 to get a predicted rate of spread of approximately 7 chains per hour. At this point, use the nomograph for fuel model 5 and work only in the upper right-hand quadrant (shown in fig. 2). Enter the nomograph as shown on the right-hand axis at 7-percent moisture content. Draw a horizontal line to the left until the line intersects the 100-percent live fuel moisture curve. Draw a line (A) at that intersection, extending vertically through the quadrant. Then take the rate of spread value calculated earlier (7 chains per hour) and enter it on the axis labeled "Rate of spread, chains per hour" at the value of 7. Draw a line extending to the right as shown in figure 4 until the line intersects the previously drawn line at a flame length value of just over 3 feet. If desired, Byram's fireline intensity can be determined from figure 3 at about 60 Btu per second per foot.
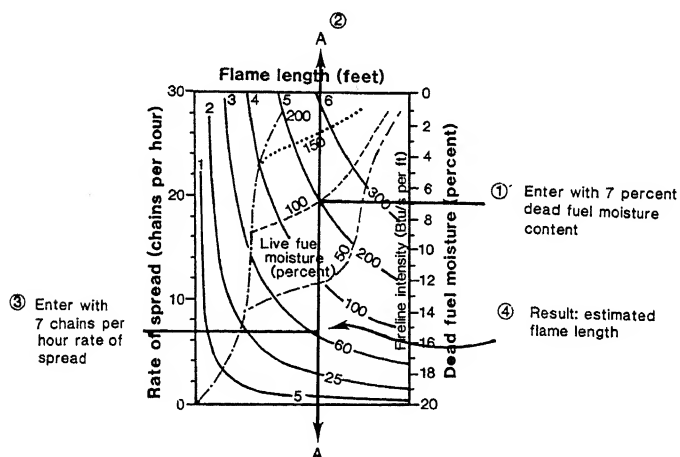

Figure 4.—Use of NFFL fuel model 5 (see fig. 2) to estimate flame lengths in fires in black spruce forests.